Observations and Simulations of Diurnal Effects Contributing to the Modification of the Coastal Marine Atmospheric Layer

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LONG-TERM GOALS

The goal of this project is to increase our understanding of the modification of complex atmospheric dynamics, cloudiness, and fog due to the interaction of the air, sea, and land in a coastal region. This increased understanding will lead to improvements in parameterizations of turbulence, cloudiness, and fog. In general, it will improve the episodic and seasonal forecasting of coastal weather over a wide spectrum of spatial and temporal scales.

OBJECTIVES

Specific project objectives include: 1) investigating the ability of mesoscale models including the Navy's COAMPS and MM5 to predict the evolution of clouds and fog in the marine atmospheric boundary layer; 2) increasing the prediction accuracy of the mesoscale models by improving the model initial and boundary conditions using satellite and aircraft measurements; 3) testing various schemes for computing wind stress over the ocean using model results and observations; and 4) implementing computational schemes for parallelization of the software to improve the performance efficiency of numerical models. The project is supported by the Office of Naval Research, Marine Meteorology and Atmospheric Effects.

APPROACH

The study was conducted using high-resolution 3D mesoscale models MM5 and COAMPS, a 1D turbulence closure model (Koracin and Rogers 1990; Rogers and Koracin 1992; Koracin et al. 2001) as well as an analysis of data from satellites, buoys, aircraft, drop-sondes, and land stations. The analysis included qualitative and quantitative comparison between the model and measurements, visualization of the simulated dynamics and the transport and dispersion of atmospheric pollutants and tracers in coastal regions using a Lagrangian random particle dispersion model (Koracin et al. 1998, 1999), and using turbulence schemes and diagnostic expressions to estimate the wind stress and the curl of the wind stress. The study also includes a novel approach to creating improved model initial conditions using satellite data.

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14. ABSTRACT

The goal of this project is to increase our understanding of the modification of complex atmospheric dynamics, cloudiness, and fog due to the interaction of the air, sea, and land in a coastal region. This increased understanding will lead to improvements in parameterizations of turbulence, cloudiness, and fog. In general, it will improve the episodic and seasonal forecasting of coastal weather over a wide spectrum of spatial and temporal scales.

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WORK COMPLETED

Our research has stressed the importance of combining observations and modeling in the study of marine meteorology. One component of our study has enhanced the analysis of marine weather through a judicious combination of a conventional observation network and special observation from satellites and buoys. In parallel with these analyses, we have conducted model simulations of the marine weather events. This two-pronged approach has allowed us to obtain independent views of the phenomena. On the analysis side, we have viewed fog formation as a scale interaction process – from large-scale to small scale forcing. The discussion of these issues from an observational viewpoint are given by Lewis et al. (2001); Lewis et al. (2002a; 2002b).

Several comprehensive numerical experiments have been completed. We have simulated the mesoscale weather on 10-11 July 2001 during DYCOMS II off the southern California coast with MM5. The model consisted of a coarse grid (horizontal resolution 9 km) and a nested grid (resolution 3 km). Besides a base run with the Eta PBL parameterization, we have completed tests with the Gayno-Seaman PBL scheme. In addition, we have completed tests with increased SST to investigate the effects of the initial SST on the structure and evolution of the marine layer. We have analyzed COAMPS results with 54, 18, and 6 km horizontal resolution on three grids for the same case that was ran by FNMOC in Monterey and compared with aircraft and drop-sonde data.

In order to investigate the month-long spatial and temporal mesoscale characteristics of the marine airflows along the US West Coast, we have performed simulations for all of June 1999 using MM5. Koracin and Dorman have already simulated and analyzed coastal dynamics for all of June 1996 and, consequently, this new study will offer the possibility of comparing warm season dynamics during two different years. For this month-long simulation, we set up a model grid with 149x191x35 grid points with a horizontal resolution of 9 km. We are currently evaluating model results using satellite and buoy data. In addition, summer wind direction anomalies along the California coast have been examined using buoy data for three years at five locations. For that case, we have performed atmospheric (MM5) and dispersion (Lagrangian random particle (LAP) model) simulations of the event on 26-27 June 1996 characterized with significant wind rotation within the diurnal cycle. Since the application of our developed LAP model to the simulation of the transport and dispersion of military emission sources in coastal regions requires an intense computing effort, we have collaborated with the University of Oklahoma to adapt the model code for parallel processing to be run on multiprocessor computers.

We have also collaborated with scientists at NCAR to perform adjoint model sensitivity studies related to the synoptic forcing that leads to strong surface wind fields. We are currently analyzing the model simulation (along with associated adjoint) of an event in March 2002.

It should be mentioned that the P.I. on the project, a graduate student (N. Adhikari), and a computer programmer (T. McCord) attended a COAMPS Training Course in Monterey 4-6 September 2002).

RESULTS

Our recent work that compared aircraft observations with output from the COAMPS and MM5 models has indicated that the predicted marine layer depth is much too shallow. The error in prediction is due to the inaccurate initial and boundary conditions from the large-scale models. Figure 1 shows vertical profiles of the ambient temperature as measured during a recent DYCOMS field program by aircraft and as simulated by COAMPS and MM5. Figure 1 demonstrates the difficulties that face regional and mesoscale models in accurately predicting the structure of the atmospheric boundary layer over the ocean. Both models show similar stability within the boundary layer as well as location of the inversion and stability aloft. It appears that COAMPS has more accurate information on the sea-surface temperature as compared to MM5 and thereby simulates a stronger inversion. It should be mentioned that in this case, the MM5 SST was increased by 2 degrees as part of sensitivity tests. However, it is important to notice that both models significantly underestimate the inversion base and clouds were not simulated. As a consequence, the following physical processes are affected: radiative heat transfer, turbulence, and stability within the entire boundary layer. In order to improve mesoscale simulations of the cloudy marine layer over the ocean, together with Dr. J. Powers from NCAR we are currently developing a method of implementing more accurate model initial and boundary conditions using satellite-derived SST and cloud-top temperature.

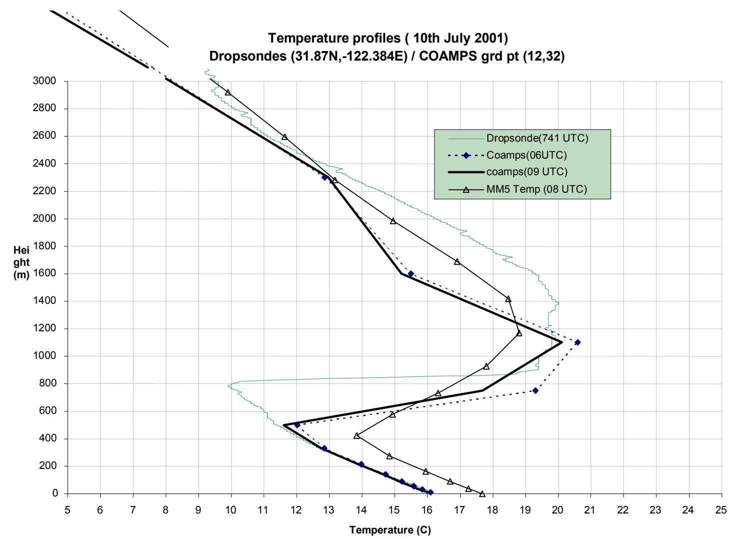

Figure 1. Vertical profiles of ambient temperature as measured by an aircraft drop-sonde and simulated by the COAMPS and MM5 models on 10 July 2001 during DYCOMS II.

Simulations of mesoscale weather along the US West Coast using MM5 with a horizontal resolution of 9 km were performed for all of June 1999. The simulations have revealed significant modification of the flow in the coastal zone with overall dynamics characteristics similar to the results from Koracin and Dorman (2001) in simulating all of June 1996. The predicted winds in the offshore region were evaluated using SSMI satellite data (Fig. 2). The figure shows the MM5 prediction accuracy of the spatial structure and magnitude range of the surface winds over the ocean (Beg-Paklar et al. 2001; Koracin et al. 2002; Dorman et al. 2002).

An analysis of observations and simulations of a significant wind rotation event on 26-27 June 1996 using MM5 and the Lagrangian random particle model have revealed the strong impact of the marine layer penetrating inland on the modification of the boundary layer over the land. The penetration is spatially inhomogeneous in response to coastal topography (Fig. 3) and induces heterogeneous anomalies in the horizontal and vertical thermodynamic structure of the boundary layer.

Koracin et al. (2001a) showed that is essential to use both observations and modeling to develop a conceptual model of the formation and evolution of offshore fog in a Lagrangian framework. An analysis of the 3D simulations (Koracin et al. 2001b) indicates that the cloud/fog top cooling is definitely a process that can dominate surface forcing and entrainment and, in conjunction with increased moisture, can lead to condensation. The results also indicate that the diurnally variable land-driven circulations significantly impact the dissipation of the fog.

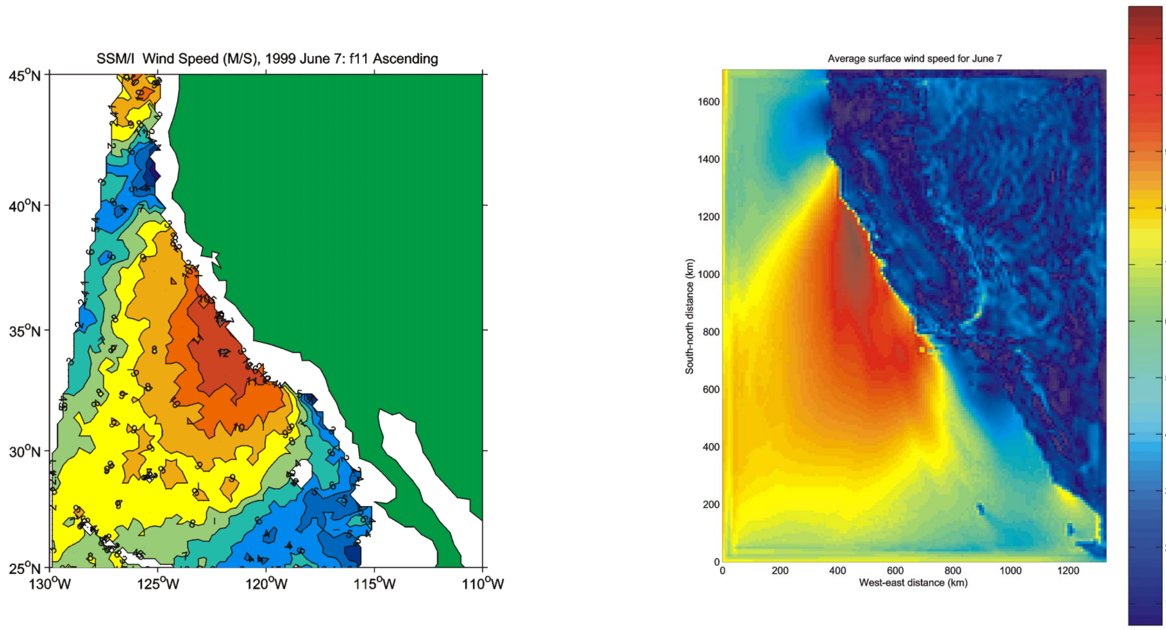

Figure 2. Surface wind speed on 7 June 1999 as derived from the SSMI satellite data (left panel) and predicted with the MM5 atmospheric model (right panel).

A developed method of parallelizing the LAP model code suggests that significant improvement of the model execution efficiency can be achieved by splitting the code into a variable number of segments - the efficiency appears to be 12 times greater by using 16 processors as compared to a run on one processor. The efficiency curve is steepest between 4 and 12 processors, which shows the fastest improvement of efficiency as a function of increasing the number of processors.

IMPACT/APPLICATIONS

The results of this study will improve the predictability of wind, turbulence, clouds, and fog in coastal areas. This will aid in decision making and in the performance of low-level airborne and sea-based naval operations. The results may be applied to other coastal areas worldwide.

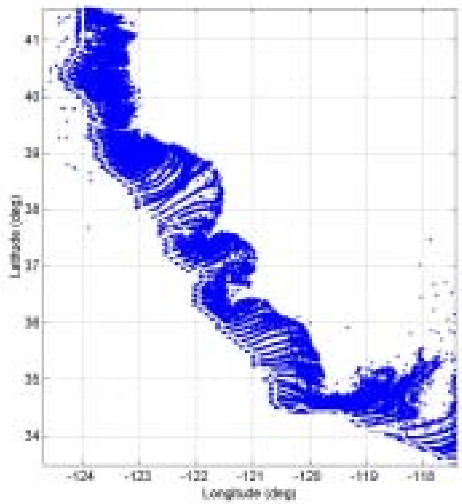

Figure 3. Low-level inland penetration of the marine layer along the coast of California is simulated using a Lagrangian random particle model, which disperses particles released from 105 sources along the coast. The marine layer flow during this period turns from northwesterly to onshore.

TRANSITIONS

The major thrust of this research is to enhance existing and develop new methods of improving mesoscale predictions of the cloudy marine atmospheric boundary layer using satellite and special field program data collected over the ocean. Improved model horizontal and vertical resolutions will allow the use of buoy observations for the model's Four Dimensional Data Assimilation (FDDA) and let us achieve more accurate mesoscale and microscale prediction of the coastal marine layer and consequently further understand air sea interaction and ocean forcing by atmospheric processes. The emphasis will be also on improving evaluation methods for atmospheric and dispersion models.

RELATED PROJECTS

Dr. Koracin is a co-P.I. on ONR Project entitled "Boundary layer marine stratus: Diurnal variability in microphysics." Currently COAMPS results are being evaluated using satellite, aircraft and drop-sonde data collected during DYCOMS II. He is also a co-P.I. on the ONR Project entitled "Multispectral Remote Sensing and COAMPS Model Analysis Methods for Marine Cloud Structure, Entrainment Processes and Refractivity Effects" focusing on the use of satellite data to evaluate COAMPS and MM5 results and develop a method of improving model initial and boundary conditions. With Dr. Clive Dorman of the Scripps Institution of Oceanography, San Diego, he is investigating dynamical processes in the coastal MABL in support of Scripps' NSF-COOP project entitled "Wind Events and Shelf Transport"; they are also conducting a project entitled "Atmospheric intensive modeling of the wind field in the Santa Barbara channel and Santa Maria basin" to investigate the spatial and temporal structure of the wind stress and the wind stress curl. Dr. Koracin is himself conducting a UCAR-COMET project focusing on the use of operational network data from DOT stations for model FDDA to improve mesoscale forecasts in complex terrain. Drs. Koracin and Lewis are co-P.I.s on a DOD SERDP project entitled "Development and validation of a predictive model to assess the impact of coastal operations on urban scale air quality," focusing on an integrated predictive tool composed of an atmospheric, dispersion, and chemical model to be used for forecasting the impact of military emissions in coastal regions.

SUMMARY

The study contributes to the evaluation of mesoscale models (COAMPS, MM5) in predicting the evolution of the cloudy marine layer and using satellite and aircraft data to improve the accuracy of the mesoscale forecast of atmospheric processes over the ocean. It also contributes to the understanding of the air-sea interaction and the evolution of offshore clouds and fog and reveals the significance of diurnally variable land circulations on the coastal dynamics and cloudiness. A novel approach in using the Lagrangian random particle model to simulate the penetration of the marine layer inland during the wind-rotation event has provided insight into the modification of the boundary layer over the land in response to the penetration of the marine layer.

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